Biomechanics of Running

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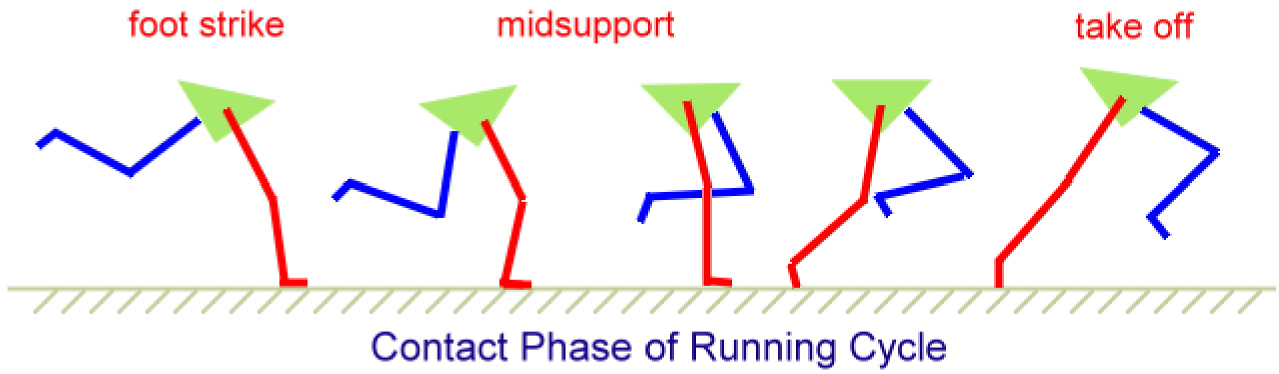
Readings

1. Hamilton, N., & Luttgens, K. 2002. Kinesiology, Scientific Basis of Human Motion, 10th ed. Boston, MA: McGraw-Hill. Chapter 19, pp. 480-484.
2. Adelaar, R.S. 1986. The practical biomechanics of running. American Journal of Sports Medicine 14:497-500.
3. Cavanagh P.R. 1987. The biomechanics of the lower extremity action in distance running. Foot and Ankle 7:197-217.

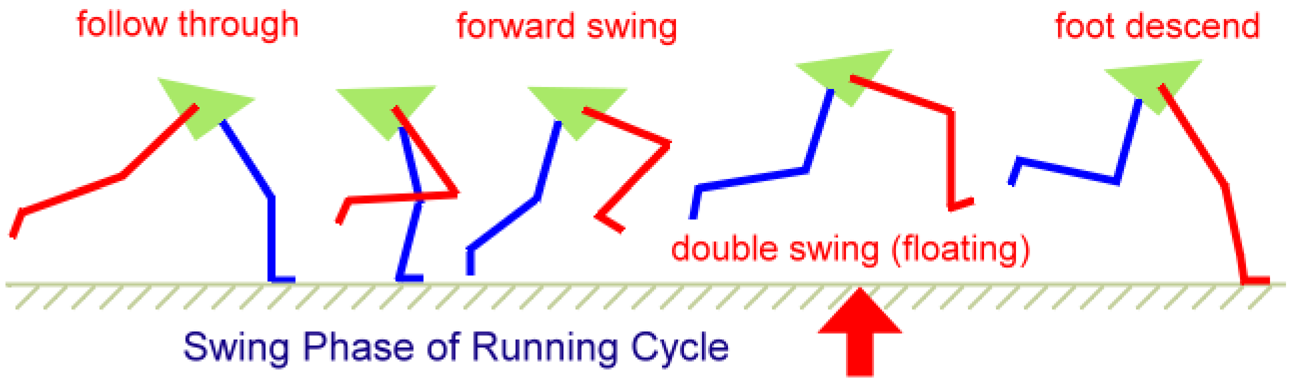
Characteristics of Running Cycle

Running Cycle

- contact phase (support phase; drive phase)： one foot is in contact with the ground, i.e., from foot strike to toe-off
    - foot strike
    - midsupport
    - take off

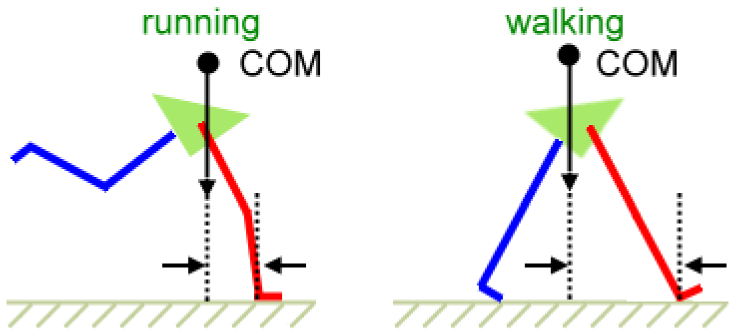


- swing phase： the lower extremity is swinging through the air, i.e., from toe-off to foot strike
    - follow through
    - forward swing
    - foot descent



Characteristics of Running

- stride length and frequency tend to increase with increased running speed
    - stride length depends on leg length, range of motion of hip, and strength of leg extensors
    - stride frequency depends on speed of muscle contraction and the skill of running
    - for speeds over 7 m/s, a increment in stride length is small but the stride frequency is significantly greater
- Both feet tend to fall on the same line along the path of progression.
- With increasing running speed, duration of contact period decreases but that of swing phase increases.
- As the foot strikes on the ground, the foot is in front of the COM of the body but the distance from foot contact to the COG is shorter in running as compared to walking. This distance becomes shorter with the increase of the speed.



Distance from Foot Contact to Body COG

- In barefoot running, the degree and duration of maximum foot pronation are increased as compared to that in running with shoes and/or foot orthoses.

Comparisons of Running with Walking

- to distinguish walking from running
  - a double swing phase during running while a double support phase during walking
  - the body is totally airborne for a period of time during running whereas at least one part of the body (usually indicating foot) contact the ground for the whole gait cycle during walking

- comparisons of kinematic and kinetic parameters of running with those of walking

	running	walking
entire cycle	swing phase longer	stance phase longer
duration of stance phase	shorter	longer
double support period	absent	present
duration of swing phase	longer	shorter
floating period	present	absent
stride length	longer	shorter
stride freqency	higher	lower
position of body COM	lower	higher
vertical oscillation of body COM	less	more
linear and angular velocity of lower extremity	faster	slower
required ROM	greater	less
muscle activities	greater	less
leg drive during swing phase	muscular	momentum (pendulum)
foot progression line	1 line along midline of body	2 parallel lines
ground reaction force	2.5~3 times body weight	~90% of body weight

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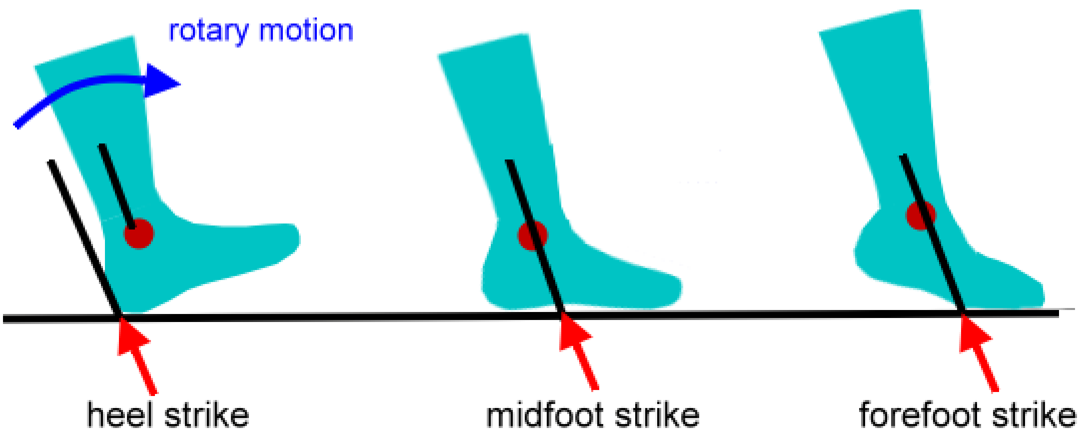
Biomechanical Analysis of Running

Foot Strike

- patterns of foot strike
    - heel strike： better for long-distance running because the heel pad has a better ability to absorb high impact force
    - midfoot strike or whole-foot strike
    - forefoot strike
        - only can be used in sprinting
        - metatarsalgia or stress fracture of the central metatarsal bones commonly occurs in the jogger with forefoot strike because of repetitive large loads onto the central metatarsal heads

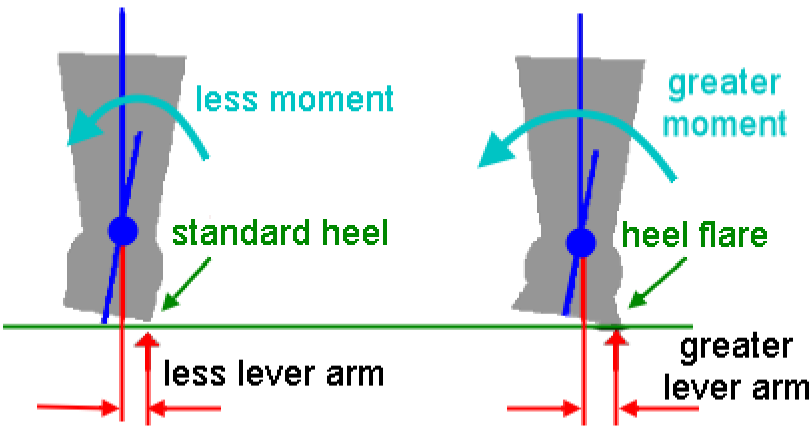


Different Foot Strike Patterns

- At the moment of foot strike, the foot is slight supinated with the tibia in some external rotation.
- The most important event during foot strike is to absorb the initial impact of the foot striking the ground through
    - rapid extension of the hip
    - flexion of the knee
    - internal rotation of the tibia
    - pronation of the subtalar joint
    - shoes and/or orthoses
- initial impact (impulse)

- impulse = $\boldsymbol{F} \times t$
- initial ground reaction force = 2.5~3 times body weight, depending on the running speed
- heel pad has better ability to absorb initial impact than other adipose tissues in human body
- improvement in materials of shoes (e.g. air-cushioned shoes) or ground surface (e.g. PU or wooden surface) may decrease the initial impact

- effect of lateral flare
  - common used in jogging shoes because the heel flare increases base of support of the heel, resulting in decreased impact force per unit area at the moment of initial contact
  - Heel flare shifts the initial contact point laterally, which increases length of the moment arm (lever arm) and then increase amount of ankle moment. This increase in ankle moment facilitates rapid pronation of the subtalar joint at the moment of landing, decrease the possibility of lateral ankle sprain



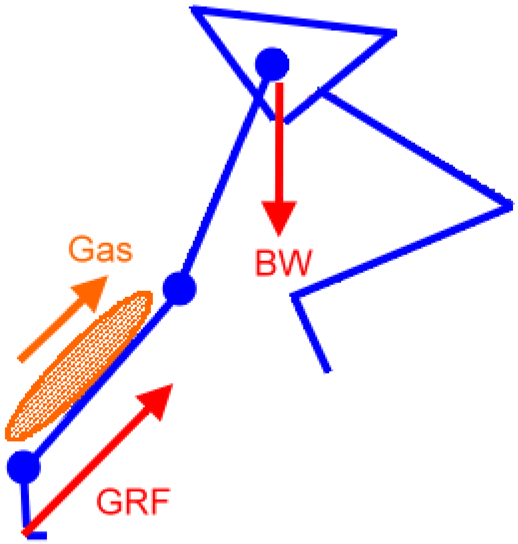
Shoes with Lateral Heel Flare Prevent Ankle Sprain
(Back View)

Takeoff

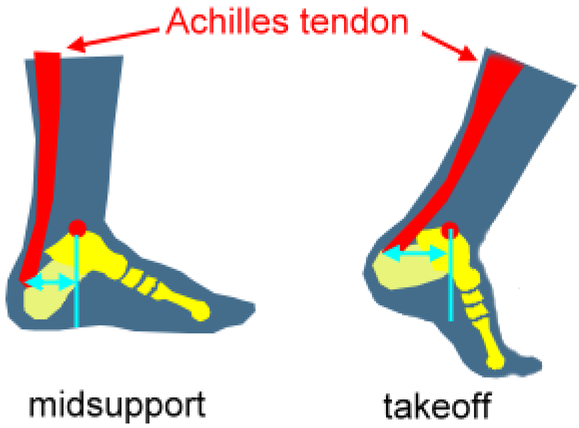
- the greater the power of the leg drive, the greater the acceleration of the runner (F = ma)
- to make the foot act as a rigid lever to propel the body forward through
  - supination of the subtalar joint
  - locking of the midtarsal joint
  - dorsiflexion (extension) of the MP joint of the big toe
- impulse = $\boldsymbol{F} \times t = m \times \boldsymbol{a} \times t = m \times \boldsymbol{v}$ = momentum
  - since running is a forward motion of the entire body, the horizontal component of the momentum is much more important than the vertical component
- momentum： a product of mass and velocity
  - momentum = mv
  - impulse-momentum relationship： any changes in momentum equals to the impulse that

produced it

- concentric contraction of the gastrocnemius muscle
  - the moment arm of the Achilles tendon increases during takeoff



Force Actions at Takeoff



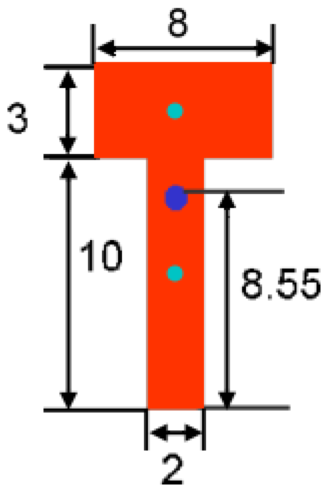
Moment Arm of Achilles Tendon Increases at Takeoff

- moment of inertia is greatest at take-off during the entire running cycle
- the larger distance the body will move during swing phase depends on
  - less angle of takeoff
  - higher speed of body projection at takeoff
  - less difference in the height of COM at the moment of takeoff and landing

Swing Phase

- reduce the moment of inertia by lifting the knee and the hip close to the body
  - increase ROM of the lower extremity to bring the mass of the swing leg close to the hip and increase the angular velocity of the swinging leg
- moment of inertia
  - definition： the property of an object that causes it to remain in its state of either rest or motion (Hamilton & Luttgens, 2002)
  - $I = I_0 + Ar^2$
    where $I_0 = I$ about centroid axis
    A = area
    r = distance
  - moment of intertia about centroid axis at different fixed-shape objects
    - circular area:： $I_0 = (1/4)\,\pi r^2$

    - rectangular area : $I_0 = (1/12)\, b\, h^3$
    - Traingular area : $I_0 = (1/36)\, bh^3$
  - example : determine moment of inertia around centroid axis of a T-shaped beam



$I = \Sigma I_0 + Ar^2$
$= [(1/12)(2)(10)^3(2)(10)(8.55-5)^2] + [(1/12)(8)(3)^3(8)(3)(4.45-1.5)^2]$
$=645.6$

  - According to Newton's first law of motion, force is needed to change the velocity (amplitude and direction) of an object.
  - moment of inertia is greatest at take-off and least after acceleration has ceased
- clearance of the foot from the ground is completed by
  - ankle dorsiflexion
  - knee flexion
  - hip flexion
- distance of a body moving in the air depends on
  - the angle of take-off i.e. ths distance of the body COG ahead of take-off point
  - the speed of the body projection at take-off
  - the height of the COM at take-off and landing
- muscle activities of the lower extremity during swing phase

	joint motion	force for movement	muscle used
hip	flexion	muscle	iliopsoas + rectus femoris (concentric)
knee	first 2/3 : flexion last 1/3 : extension	first 2/3 : momentum last 1/3 : muscle	first 2/3 : -- last 1/3 : hamstrings (eccentric)
ankle	dorsiflexion	muscle	tibialis anterior + toe extensors (concentric)

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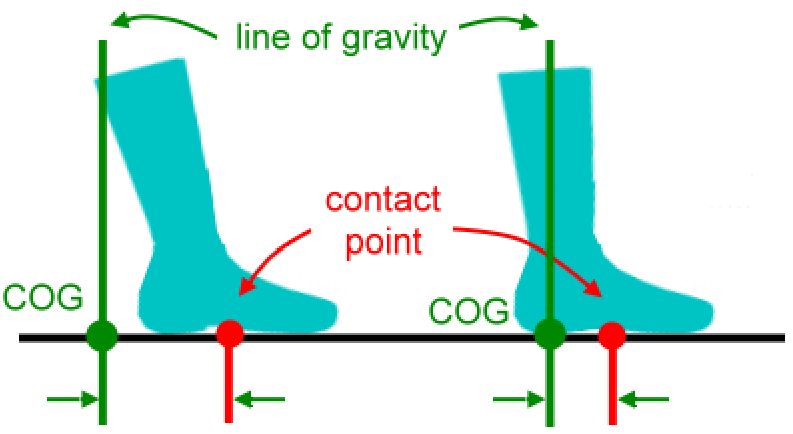
Special Considerations in Sprinting

Definition

- running distance < 400 m
- stance phase of sprinting is only 22% of the running cycle

Efficiency of Running -- to get maximum horizontal velocity without falling

- increase in stride length
  - speed = stirde length × stride frequency
  - stride length is dependent on leg length, angle of hip raising, and strength of the leg extensors
  - stride frequency is dependent on speed of muscle contraction and the skill of runner
- decrease in vertical displacement of the COM
  - Given the same ground reaction force, the smaller the vertical component of the leg drive, the the greater the horizontal component of running velocity
- foot strike close to center of gravity
  - better to use midfoot or forefoot strike in order to have line of gravity passing through the ankle joint
  - If the foot strikes ahead the line of gravity, the ground reaction force creates a upward and backward moment that will retard forward motion. Therefore, as the running speed increases, the distance between the contact point of foot strike and the center of gravity decreases in order to reduce the stance and facilitate propulsion.



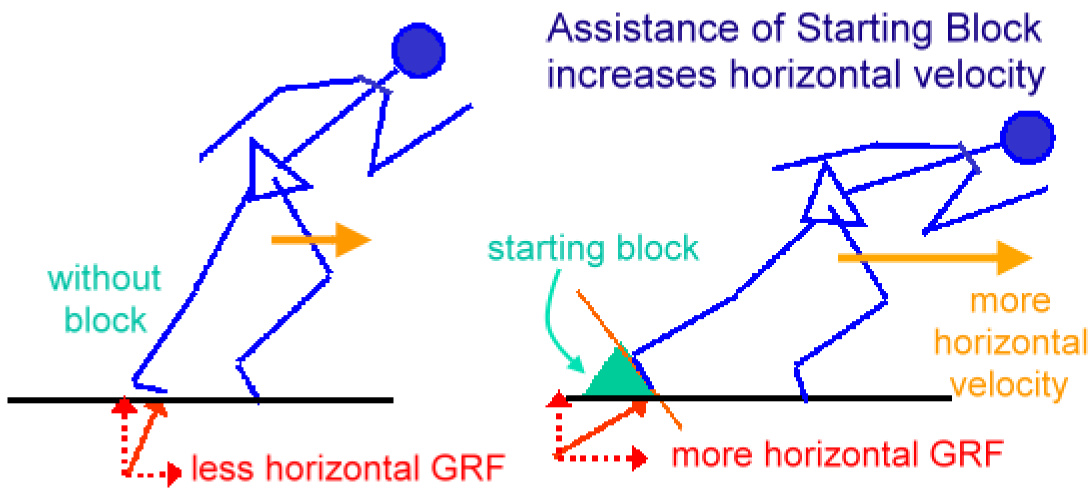
Foot Strike Close to COG Facilitates Propulsion

  - If the foot strikes behind the line of gravity, the ground reaction force create a upward and forward moment that will make the body fall forward
- decease in lateral movements
  - motions occurring in the entire lower extremity should be in the sagittal plane
  - the arm movement is used to counterbalance rotation of the pelvis only
- shortening of swing leg
  - the shortening of swing leg shortens the moment arm to decreases moment of inertia and

increase forward velocity
    - the higher the knee lifts, the greater the velocity is created.
- decrease internal resistance from the viscosity of the soft tissues
    - warm-up and stretching exercises can reduce the viscosity of the soft tissues of the participating limbs

Sprint Start

- crouching start (蹲踞起跑)
    - the greater the power of the leg drive, the greater the acceleration of the runner (F = ma)
- assistance of starting block (起跑架)
    - make it possible that trunk inclines forward without overstretching the Achilles tendon
    - provides a tilting surface against which the foot pushes horizontally while using total hip, knee, and ankle extension
    - the horizontal push-off force (impulse) results in an increased horizontal velocity (momentum)



Efficiency of Running

- decrease in vertical displacement of the COM
- foot strike close to line of gravity
- decease in lateral movements
- shortening of swing leg
- increase in stride length

Shortening of Swing Leg

Increase in Stride Length

- During the acceleration phase of the race, the trunk is more erect so that the length of the stride increase dependent on the angle that the hip joint raises

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Biomechanics of Jogging

Definition

- running > 1500 m
- classification of long-distance runners (Brody, 1980)
    - jogger： run 3-20 miles per week at a rate of 9-12 minutes per mile
    - sports runner： run 20-40 miles per week and participate in "fun runs" or races of 3-6 miles
    - long-distance runner： run 40-70 miles a week at a pace of 7-8 minutes per mile and may compete in 10,000 m races or marathons
    - elite marathoner： run 70-200 miles a week with a pace of 5-7 minutes per mile

Characteristics of Jogging

- stance phase decreases to 31%
- should prevent repetitive impact stresses
    - heel strike or midfoot strike
    - medial and lateral flares
    - better material for heel pad

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